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ANNOTATED LIST OF SPECIES

Medium-sized and large bodied mammals of Marshall Wetlands, a proposed protected area in Liberia

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Abstract. Liberia comprises 43% of the upper Guinean tropical forest of West Africa, a global hotspot with high levels of biodiversity and endemism succumbing to accelerated rates of deforestation. Due in part to the country's past civil war, knowledge about much of Liberia's remaining local biodiversity is limited. To help fill this gap, we surveyed medium-sized and large-bodied mammals in a proposed protected area, the Marshall Wetlands, in Margibi County, Liberia. Using 21 camera traps, in an effort of 33,120 hours, and track surveys along trails, between July 2022 and May 2023, we confirmed the presence of 13 medium-sized and large mammal species. Of these, four species have some degree of threat in the IUCN Red List. Despite its proximity to the capital city of Monrovia, the Marshall Wetlands comprise significant biodiversity, highlighting its conservation value and reinforcing the value of improved protected status.

Key words. Biodiversity, camera-trapping, mangrove, species list, tropical forest, West Africa

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INTRODUCTION

Liberia is home to 4.33 million ha of forest (Christie et al. 2007), which includes 42% of West Africa's remaining intact lowland rainforest, the upper Guinean tropical forest. As the largest remaining forest areas in West Africa (Christie et al. 2007), they hold great biological importance. Civil conflict occurring in the years 1989–1997 and 2002–2003 prevented field studies in Liberia, meaning species being hosted are not on recent record. The country potentially hosts several yet unknown species and lies within a conservation priority ecoregion (Jenkins et al. 2013). In addition, Liberia has high levels of biodiversity and falls within the richest 5% of land area for threatened amphibians, birds, and mammals (Jenkins et al. 2013).

Biodiversity loss is a significant issue in Liberia, where an expanding human population, demands for forest products, and inadequate law enforcement pose acute threats to forests and their inhabitants (Covey et al. 2014). Most species are threatened by hunting (Bene et al. 2013) and many by the illegal live pet trade (Verschuren 1983). In fact, hunting is the most frequently encountered anthropogenic threat found across the country, followed by logging, mining, and the extraction of non-forest timber products (Tweh et al. 2015). Estimates indicate that annual wildlife harvests in Liberia hold one of the highest per capita offtake rates in Africa (~150,000 tons; Anstey 1991), and that this threat is on the rise (Covey and McGraw 2014).

The Liberian government has committed to preserving 30% of the country's remaining forests by 2030, setting the course for establishment of protected areas that prioritize biodiversity rich regions (Liberia 2019). One of these regions, the Marshall Wetlands Proposed Protected Area (23,813 ha), located in Margibi County, along the central coast of Liberia, is recognized as a Ramsar site of international importance (e.g., wetlands with recognized importance as waterflow habitats; Ramsar Convention Secretariat 2014). This area comprises both savannah and secondary forests further inland, and mature mangrove trees along the coastline that help negate flooding and shore erosion (RSI Service 2006). Mangroves are particularly relevant given their role in reducing erosion and absorbing storm surge impacts during extreme weather events. The Marshall Wetlands are important to nearby local communities who use the area's three rivers for transportation and rely on fish and other natural resources throughout the landscape. However, these human pressures also threaten the area's biodiversity; it is estimated that the rate of mangrove deforestation in the country could be as high as 65% since 1980 (FAO 2016). Increasingly, Liberia recognizes the importance of mangroves as valuable habitats for wildlife, including many charismatic and endangered species, and the valuable ecosystem services they provide, including in terms of carbon sequestration.

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Few studies have been conducted to identify current population, threat, occurrences, and distribution of mammals in Liberia (but see Barrie et al. 2007 and Amin et al. 2022), especially in mangrove habitats. Mammals are one of the most complex groups in the animal kingdom, possessing diverse traits that enable them to thrive in a wide range of ecological niches, including both aquatic and terrestrial environments. Mammals are also one of the groups most affected by deforestation and fragmentation, due to their need for large areas of use in comparison with other groups, and their poor ability to disperse through open and/or urban areas (Michalski and Peres 2007). Mammals play several key ecological roles, including seed dispersal, herbivory, and control of lower trophic levels (Lacher et al. 2019). The Marshall Wetlands are potentially home to a rich mammal assemblage but lack of information on species' population, distribution, and degree of threat poses a major challenge for conservation practitioners in Liberia. To help address this gap, this study provides current information on existing medium-sized and large-bodied mammal species found in the Marshall Wetlands.

STUDY AREA

The study was conducted in Charlesville, Marshall Wetlands, Margibi County, Liberia, situated on the fringe of some of the agroecological zones of the country, approximately 100 km from Monrovia, the country's capital. The area, currently proposed as a protected area is surrounded by over 60 communities in Grand Bassa and Margibi Counties, with a combined population of 85,632 people. The survey area included land recently designated for conservation purposes under a long-term community lease, as well as areas without active protection measures.

The Marshall Wetlands comprise six islands and three rivers. With an area of 12,168 ha, Marshall Wetlands are covered mostly by mature mangrove forests reaching up to 30 m, with secondary forests and savannah woodland further inland (Figure 1). The major sources of livelihood for people living on the fringes of the Marshall Wetlands are charcoal production, harvesting of mangrove trees, fishing, and collection of non-timber forest products. Liberia's rainy season starts in April, peaks in July, and ends in November. The dry season covers November to April, with a dry wind from November to February. It has a coastal climatic condition with relative humidity varying between 90 and 100% and has a mean annual temperature of 26 °C (RSI Service 2006).

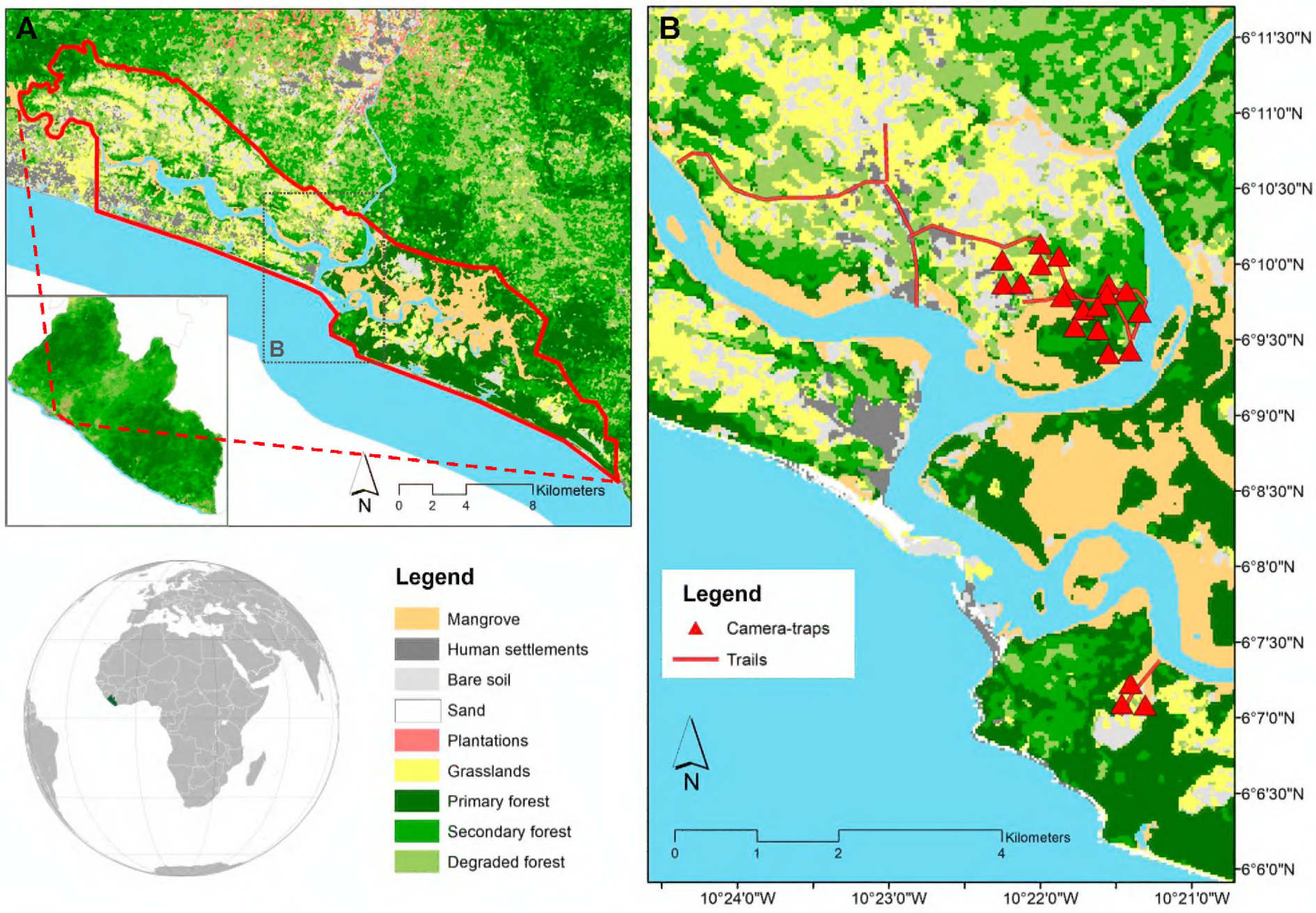

Figure 1. Location of study area where mammals were surveyed, using a land-cover map derived from de Sousa et al. (2023). **A.** Location of the Marshall Wetlands Proposed Protected Area (red-delimited), in Liberia. **B.** Camera-trap (red triangles) and trail (red lines) locations used to survey mammal assemblages within the Marshall Wetlands.

Table 1. Geographic coordinates (decimal degrees), latitude (meters), sampling effort (in hours) and number of species detected in each of the 21 camera-traps installed in the Marshall Wetlands Proposed Protected Area, in Liberia.

Camera trap ID	Geographic coordinates		Altitude (m)	Sampling effort (h)	No. of species detected
	Latitude	Longitude			
CT 01	06.1640	-010.3591	8	1510	6
CT 02	06.1204	-010.3566	11	1509	2
CT 03	06.1568	-010.3591	10	1509	3
CT 04	06.1645	-010.3707	8	1509	3
CT 05	06.1571	-010.3567	12	1509	3
CT 06	06.1675	-010.3645	15	1509	2
CT 07	06.1689	-010.3666	9	1509	6
CT 08	06.1671	-010.3708	10	1509	2
CT 09	06.1182	-010.3576	11	1509	5
CT 10	06.1645	-010.3687	8	1509	3
CT 11	06.1638	-010.3637	18	1509	6
CT 12	06.1180	-010.3550	5	1509	1
CT 13	06.1616	-010.3619	7	1509	3
CT 14	06.1666	-010.3666	14	1509	3
CT 15	06.1637	-010.3571	9	1509	4
CT 16	06.1633	-010.3593	22	1509	4
CT 17	06.1631	-010.3642	10	1509	5
CT 18	06.1594	-010.3602	15	1509	7
CT 19	06.1613	-010.3556	21	1509	5
CT 20	06.1620	-010.3603	8	1509	6
CT 21	06.1597	-010.3628	10	1509	7

METHODS

Mammals were surveyed along trails and dirt roads in the Marshall Wetlands Proposed Protected Area, selecting the most suitable routes for walking and most likely to have higher wildlife presence (i.e., lower human presence). In addition, one area accessed by a river was included to represent a more preserved area, not accessible by vehicle. Trail selection relied on criteria such as geographic location within the area, human presence, and representation of the different habitats that exist in the protected area.

Medium-sized and large bodied mammals were sampled using 21 camera traps (Bushnell HD model 119739), in addition to direct and indirect mammal observation along trails. On each trail surveyed, camera traps were installed at a minimum distance of 250 m from one another, and at a height of 60 cm from the ground floor. Camera traps were set using the motion-triggered setting. Yet, if continuously triggered, the sequence of three pictures was only taken after every 2 minutes. Cameras were also set with the highest quality setting both for the photos and sensor, with the goal of covering the entire trail. Trails included the three main habitats present in the area, primary and secondary forest, mangrove, and nearby human settlements. The camera traps remained active between July 2022 and May 2023, with a total effort of 33,200 hours. Many species of medium-sized and large mammals have elusive behavior, occurring in low densities and having nocturnal habits, making it difficult for researchers to record them directly, making strategic locations and remote operation important tools for recording wildlife (O'Connell et al. 2010). Geographic coordinates, altitude, sampling effort, and number of species detected for each of the 21 cameras is included in Table 1.

To complement the mammal species being recorded on camera traps, between April and May 2023, every trail targeted in this study (range length of 500–2500 m) was covered one time by foot, at a maximum speed of 1 km/h, between the hours of 6:30 and 17:30. This method allowed us to obtain visual and auditory records (vocalizations), animal carcasses, and indirect evidence (i.e., mammal signs such as footprints, scratches, feces, and burrows), indicating the presence of mammals, with a total effort of 36 h of active search. Mammal signs were recorded with a ruler, photographed, and georeferenced. In Liberia, research permits are not required for studies not involving the collection of biological material, so that no permit was obtained in this study.

We considered all mammal species larger than 1 kg as medium-sized and large and identified each record to the lowest taxonomic level possible using mammal guides and personal expertise of the field team (Kingdon 2015). Data collection via data sheets included geographic coordinates obtained by a GPS receiver, date

Figure 2. Photographs showing mammal survey methods and records. **A.** Researchers searching for mammal tracks along trails. **B.** Example of a track from *Aonyx capensis*. **C.** Example of deployed camera-trap, facing a cleared area. **D.** Example of deployed camera-trap, attached to a tree trunk. (Photos: Paula Prist and Allen Gweh).

and time of deployment, battery status, number of images taken, and date and time of retrieval. In addition, listings under the Convention on International Trade of Endangered Species of Fauna and Flora Appendices (CITES 2023) and the IUCN Red List of Threatened Species (2023) were accessed for each recorded species to assess species conservation status. To evaluate the effectiveness of our camera-trapping surveys, we used the iNEXT R package (Hsieh et al. 2016) to generate a sample-based rarefaction curve using the order $q = 0$ of the Hill numbers. This analysis was conducted using R v. 4.1.2 (R Core Team 2021).

RESULTS

The survey recorded 13 native species of medium-sized and large-bodied mammals, organized in five orders and 10 families. Carnivora and Artiodactyla were the orders with most species, with five species belonging to three families each, followed by Rodentia, with two species from two families. The orders Pholidota and Primates were represented by one species each. The most represented family was Bovidae with three species, followed by Viverridae and Herpestidae, with two species each (Table 2). Of the 13 species recorded, the following three species were classified in the IUCN Red List in a threatened category: *Genetta bourloni* (Vulnerable), *Cephalophus jentinki* (Endangered), and *Smutsia gigantea* (Critically Endangered); *Aonyx capensis* i Near-Threatened, and the remaining 10 species have the status of Least Concern (Table 2). Camera-trapping allowed for 654 records corresponding to 12 mammal species, with nine species recorded exclusively using this method (Figure 3). However, 53 records could not be identified to the species level. Trail surveys identified 20 signs of mammals, including tracks and feces, 13 of them matching five species, while the remaining seven records could not be identified to the species level (Table 1). The African clawless otter was the only species to be exclusively recorded through trail surveys using tracks (Figure 2B).

Table 2. Mammal species recorded in the Marshall Wetlands, a proposed protected area in Liberia. For each species, we provide the scientific and common names, number of detections (including both camera-trap records and indirect records obtained along trails), sampling method through which that species was recorded (i.e., T = track; CT = camera-trap), and Red List status following IUCN (2023): LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; CR = Critically Endangered.

Scientific name	Common name	Number of records		Conservation status
		Camera-trap	Tracks	
CARNIVORA				
Viverridae				
*Civettictis civetta**	African Civet	236	6	LC
Genetta bourloni	Bourlon's Genet	3	1	VU
Mustelidae				
Aonyx capensis	African Clawless Otter		1	NT
Herpestidae				
*Herpestes sanguineus**	Common Slender Mongoose	15	2	LC
Atilax paludinosus	Marsh Mongoose	115		LC
RODENTIA				
Hystricidae				
Atherurus africanus	Brush Tail Porcupine	24		LC
Nesomyidae				
Cricetomys sp.	Giant Pouched Rat	3		LC
ARTIODACTYLA				
Tragulidae				
Hyemoschus aquaticus	Water Chevrotain	1		LC
Bovidae				
*Philantomba maxwellii**	Maxwell's Duiker	125		LC
Cephalophus jentinki[4]	Jentink's Duiker	2		EN
Tragelaphus scriptus	Bushbuck	35	3	LC
PHOLIDOTA				
Manidae				
Smutsia temminckii	Ground Pangolin	1		CR
PRIMATES				
Cercopithecidae				
Chlorocebus sabaeus	Green Monkey	41		LC

*These species are included in the CITES (2023) Appendices (i.e., they are recognized as threatened by international trade).

Viverridae

***Civettictis civetta* (Scherber, 1776)**
African Civet
Figure 3A

Observations. LIBERIA • Marshall Wetlands; 06.164, -010.359; first capture on 10.II.2022; Allen Gweh obs.; records from camera trap photos (camera-trap ID numbers 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22) and tracks; recorded in secondary forest, mangroves and primary forest; common across the study area.

Identification. This species as a pale silver or cream coat with brown-black spots, along with a dark face mask. It has large hindquarters and a mane that runs along their back (Kingdon 2015).

***Genetta bourloni* (Gaubert, 2003)**
Bourlon's Genet
Figure 3B

Observations. LIBERIA • Marshall Wetlands; 06.159, -010.362; first capture on 30.IX.2022; Allen Gweh obs.; records from camera trap photos (camera-trap ID numbers 20, 22) and tracks; recorded in secondary forest, near a stream.

Identification. This species has a cream-gray coat with dark dorsal spots that coalesce at the first two rows, and dark limbs. The tail lacks any tip coloration (Kingdon 2015).

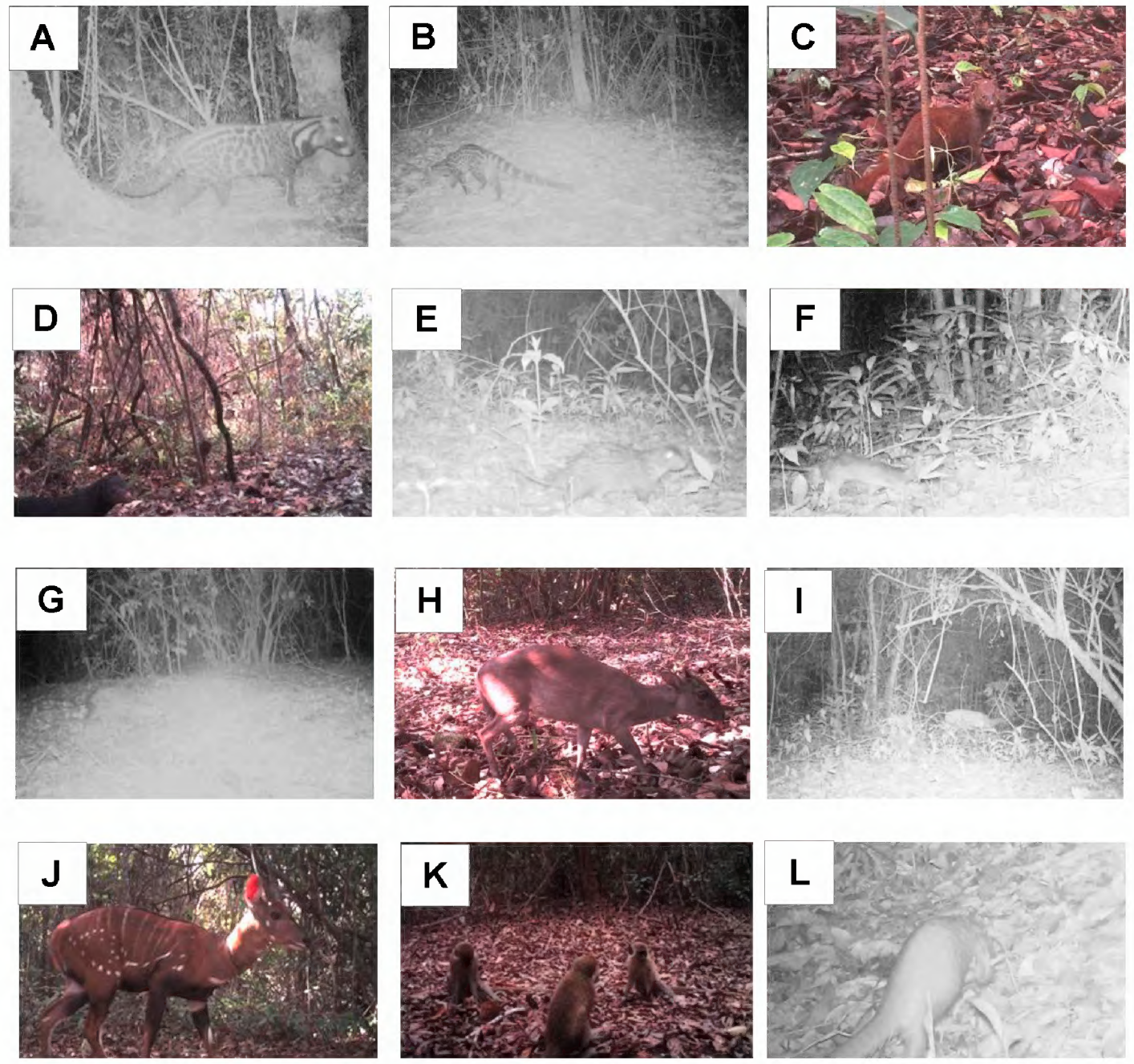

Figure 3. Camera-trap records of mammal species in the Marshall Wetlands, a proposed protected area in Margibi County, Liberia . **A.** *Civettictis civetta*. **B.** *Genetta bourloni*. **C.** *Herpestes sanguineus*. **D.** *Atilax paludinosus*. **E.** *Atherurus africanus*. **F.** *Cricetomys* sp. **G.** *Hyemoschus aquaticus*. **H.** *Philantomba maxwellii*. **I.** *Cephalophus jentinki*. **J.** *Tragelaphus scriptus*. **K.** *Smutsia temminckii*. **L.** *Chlorocebus sabaeus*.

Herpestidae

***Herpestes sanguineus* (Rüppell, 1835)**
Common Slender Mongoose
Figure 3C

Observations. LIBERIA • Marshall Wetlands; 06.159, -010.362; first capture on 10.III.2023; Allen Gweh obs.; records from camera trap photos (camera-trap ID numbers 4, 6, 8, 10, 12, 14, 18, 19, 20, 22); recorded in recorded in secondary forest, mangroves and primary forest.

Identification. This species is small and slender with coat ranging from reddish- to yellowish-brown with a cream underbelly. The tail is long, slender, and tipped with black or dark brown (Kingdon 2015).

***Atilax paludinosus* (Cuvier, 1829)**
Common Slender Mongoose
Figure 3D

Observations. LIBERIA • Marshall Wetlands; 06.164, -010.359; first capture on 10.IV.2022; Allen Gweh obs.; records from camera trap photos (camera-trap ID numbers 1, 2, 4, 6, 7, 8, 9, 10, 11, 12, 15, 17, 18, 19, 21, 22); recorded in secondary forest, mangroves and primary forest.

Identification. Medium-sized species characterized by dark brown to black coat. It has small eyes, ears barely visible, and flattened snout, pointed and slightly turned upwards. The tail is long and dark (Kingdon 2015).

Hystricidae

***Atherurus africanus* (Gray, 1842)**
Brush Tail Porcupine
Figure 3E

Observations. LIBERIA • Marshall Wetlands; 06.164, -010.359; first capture on 04.IV.2022; Allen Gweh obs.; records from camera trap photos (camera-trap ID numbers 1, 4, 8, 10, 11, 12, 15, 17, 20, 21, 22); recorded in secondary forest, mangroves and primary forest.

Identification. This species is characterized by a long body covered in protective spines of various length. The legs are short and wide with webbed feet and claws. The body is black to dark brown with a white to light-brown underside and a yellowish brushy tail (Kingdon 2015).

Nesomyidae

***Cricetomys* sp.**
Giant pouched rat
Figure 3F

Observations. LIBERIA • Marshall Wetlands; 06.164, -010.359; first capture on 12.XI.2022; Allen Gweh obs.; only three records from camera-trap photos (camera-trap ID numbers1, 12, 19); recorded in primary forest; given the potential presence of both *C. gambianus* and C. *emini*, which cannot be confidently distinguished based on morphological grounds, we could not identify the species of *Cricetomys*.

Identification. This giant rat is covered in coarse, dark-brown fur with dark rings around the eyes. The tail is long and scaly, and the head is narrow with tiny eyes. It has large cheek pouches (Kingdon 2015).

Tragulidae

***Hyemoschus aquaticus* (Ogilby, 1841)**
Water Chevrotain
Figure 3G

Observations. LIBERIA • Marshall Wetlands; 06.159, -010.362; 20.XII.2022; Allen Gweh obs.; recorded only once from camera trap photos (camera-trap ID numbers 22); recorded in secondary forest.

Identification. This species is characterized by horizontal white stripes below rows of white spots over a reddish-brown coat. A white inverted "V" marks the neck. Males have small protruding folds on the upper jaw (Kingdon 2015).

Bovidae

***Philantomba maxwellii* (Smith, 1827)**
Maxwell's Duiker
Figure 3H

Observations. LIBERIA • Marshall Wetlands; 06.156, -010.359; first capture on 10.III.2022; Allen Gweh obs.; records from camera-trap photos (camera-trap ID numbers 3, 14, 16, 17,18, 19, 20, 21, 22); recorded in secondary forest, mangroves and primary forest.

Identification. This duiker is characterized by its short legs and a slightly arched back. Females are typically larger than males, however, their coloration is consistent with a hair that is light brown. They also have short, simple horns, with two light stripes of fur running from these horns to their eyes (Kingdon 2015).

***Cephalophus jentinki* (Thomas, 1892)**
Jentink's Duiker
Figure 3I

Observations. LIBERIA • Marshall Wetlands; 06.164, -010.359; first capture on 04.IV.2023; Allen Gweh obs.; recorded only twice from camera-trap photos (camera-trap ID numbers 1 and 12); recorded in primary forest.

Identification. This is one of the largest duiker species characterized by its short legs and high weight. It has a distinctive multicolored pattern with the front part of the body marked by glossy black or brownish and the back with coarse gray or gray-brown fur. The tail is narrow, and both sexes have dark, spike-like horns that curve slightly downward at the tip. Facial markings include a pale halo around the nose and lips (Kingdon 2015).

***Tragelaphus scriptus* (Pallas, 1766)**
Bushbuck
Figure 3J

Observations. LIBERIA • Marshall Wetlands; 06.164, -010.359; first capture on 11.II.2022; Allen Gweh obs.; records from camera trap photos (camera-trap ID numbers 1, 8, 12, 16, 17, 18, 19, 20, 21, 22) and tracks; recorded in secondary forest, mangroves, and primary forest.

Identification. This species is easily recognized by its seven white stripes lining its hazel-colored fur. There is a white muzzle, white cheek marks, and a short tail. Horns are present only in males (Kingdon 2015).

Manidae

***Smutsia temminckii* (Smuts, 1832)**
Ground Pangolin
Figure 3K

Observations. LIBERIA • Marshall Wetlands; 06.163, 010.364; 22.IV.2023; Allen Gweh obs.; only one record from camera trap photos (camera-trap ID number 17); recorded in primary forest.

Identification. This species is the largest pangolin and is characterized by a long body covered in overlapping keratinized scales, and by strong forelimbs with three large claws. The head is long and narrow. The tail is shorter than other pangolins and is broad at the base (Kingdon 2015).

Cercopithecidae

***Chlorocebus sabaeus* (Linnaeus, 1766)**
Green Monkey
Figure 3L

Observations. LIBERIA • Marshall Wetlands; 06.156, -010.359; first capture on 11.IV.2022; Allen Gweh obs.; records from camera trap photos (camera-trap ID numbers 3, 8, 10, 13, 17, 18, 19, 21, 22); recorded in secondary forest, mangroves, and primary forest.

Identification. This is a medium-sized primate with a dark-blue, hairless face, which is outlined with white fur. There is golden fur with a greenish tint over the rest of the body. The tail is long and semi-prehensile (Kingdon 2015).

Mustelidae

***Aonyx capensis* (Schinz, 1821)**
African Clawless Otter
Figure 2B

Observations. LIBERIA • Marshall Wetlands; 06.162, -010.364; 03.II.2023; Allen Gweh obs.; only one record from tracks; recorded in a mangrove area.

Identification. Footprints of small-clawed otter are small, with long fingers and incomplete webbing. Most tracks showed no indication of a claw mark. We found that fore feet were smaller than hind feet (Aadrean et al. 2010).

According to the rarefaction curve based on number of records, our sampling of the mammal assemblages in the Marshall Wetlands was overall satisfactory (Figure 4). If the camera trap records were doubled, we would likely be able to only slightly increase the number of species recorded from 13 to approximately 16 species (Figure 4).

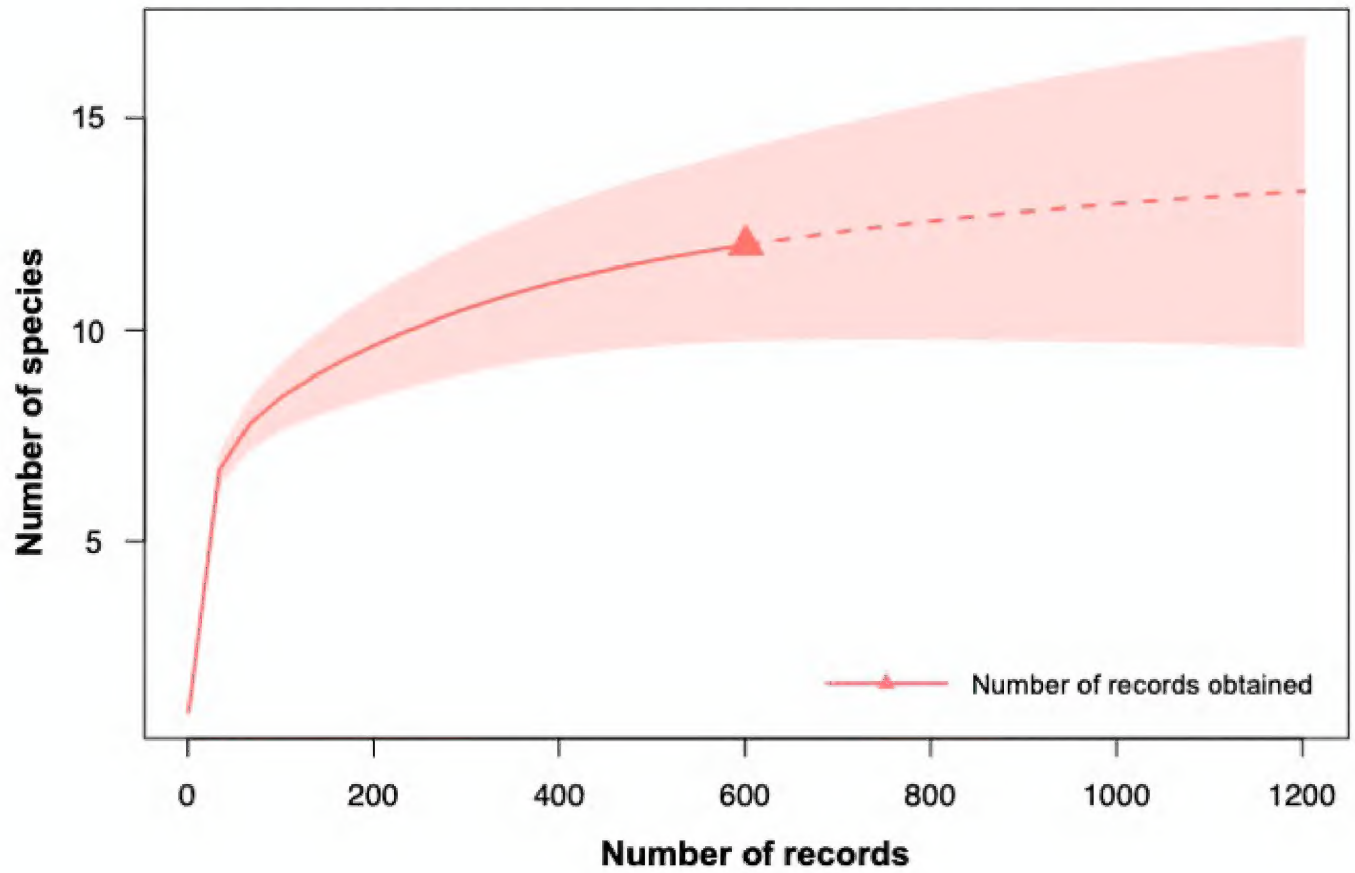

Figure 4. Rarefaction curve considering the number of camera-trap records across all 25 camera-trap locations and the number of mammal species recorded in Marshall Wetlands Proposed Protected Area, Liberia. The solid triangle represents the cumulative number of camera-trap records for the given number of observed species. Shaded areas indicate 95% confidence intervals. The curves were extrapolated into a sampling effort corresponding to double what has been observed.

DISCUSSION

Here we provide a list on the mammal biodiversity in the Marshall Wetlands region of Liberia, an area that has minimal biodiversity data from recent decades. A total of 13 native mammalian species were observed, including four threatened species according to the IUCN Red List of Threatened Species and, thus, of conservation concern. Our results indicate that, despite anthropogenic pressures such as hunting and deforestation, biodiversity can still find suitable habitats for survival in this area, highlighting the importance of the Marshall Wetlands for conservation. In addition, each of the threatened species has only been recorded a few times during our surveys. For instance, we only recorded once the Critically Endangered *Smutsia temminckii*, and twice the Endangered *Cephalophus jentinki*.

Human-disturbed landscapes are known to sustain lower biodiversity than remote areas (Gibson et al. 2011). Larger mammal species have higher spatial requirements and are subject to high hunting-interest, and they are the first to undergo local extinction (Cardillo et al. 2005). Given the site's proximity to the capital city, it is not surprising only 13 mammal species were recorded through our year-round surveys in the Marshall Wetlands. For instance, in Sapo National Park, Liberia's largest protected area, 32 mammal species have been recorded by camera-trap surveys (Amin et al. 2022). In rapid assessment surveys of midsize to large mammals in Liberia, 28 species have been recorded in Grebo National Forest, 21 species in the North Loma National Forest, and 14 species in the Gola National Forest (Barrie et al. 2007). We were able to record both common species (e.g., *Civettictis civetta*, *Tragelaphus scriptus*, and two mongoose species), and rarer threatened species, including *Smutsia temminckii*, *Genetta bourloni*, *Cephalophus jentinki*, and *Aonyx capensis*, whose presence elevates the conservation potential of the Marshall Wetlands. In addition, threatened species were relatively rare in the surveyed area, with each of them being recorded only between one and four times (Table 2). Although number of camera-trapping records is not a measure of species abundance, it has been used as a proxy for this information (e.g., Benchimol and Peres 2021). If we apply this method, our results further alert us to the urgency in promoting the protection of this area to avoid local extinction of these important species. The Marshall Wetlands are also an appropriate habitat suitability for habitat-sensitive species such as *Pan troglodytes verus* Schwarz, 1934 (Western Chimpanzee), *Loxodonta cyclotis* (Matschie, 1900) (African Forest Elephant), and *Choeropsis liberiensis* (Morton, 1849) (Pygmy Hippopotamus) (Freeman et al. 2018). In addition, the recorded mammal species further represent a variety of trophic guilds, including carnivores (e.g., *Civettictis civetta* and *Genetta bourloni*), herbivores (e.g., duikers and the bushbucks), insectivores (e.g., *Smutsia temminckii*) and omnivores (e.g., *Chlorocebus sabaeus* and *Cricetomys gambianus* rat) (Wilman et al. 2014), indicating that mammal fauna present in the Marshall Wetlands is playing an important role in the functioning of the ecosystem. Overall, our results point in the direction that increasing the protection status of this area has a high potential for effective biodiversity conservation, including that of elusive threatened species.

According to our species accumulation curves, it is possible that 2–4 additional species remained undetected using camera-trapping. For instance, we did not detect the *Cephalophus niger* Gray, 1846 (Black Duiker) or *Herpestes sanguineus* (Rüppell, 1835) (Common Slender Mongoose), both of which are typically recorded using camera-trapping and known to tolerate some level of human-disturbance (IUCN SSC Antelope Specialist Group 2016; Do Linh San and Maddock 2016). Additional species that might also be expected to be recorded as they are common in similar West African forests are *Thryonomys swinderianus* (Temminck, 1827) (Marsh Cane Rat; Child 2016), *Xerus erythropus* E. Geoffroy, 1817 (Striped Ground Squirrel; Cassola 2016), and *Nandinia binotata* (Gray, 1830) (African Palm Civet; Gauber et al. 2015). Although camera-trap locations aimed for low human presence, all cameras were deployed at close distance between each other (i.e., the distance between the two farther apart cameras was 2 km). The relatively small size of the area sampled might have further contributed to the limited number of mammal species recorded. Additional species that potentially occur in the area might be detected if the sampling effort were increased (e.g., by increasing the area covered in the surveys, increasing the number of trapping days as well as the number of trails were census take place). This study carries some potential limitations that may have affected capture of information. The area's proximity to local communities who use the forest as a source of income and food resulted in camera theft (three cameras) and loss of photo evidence. Finally, the unavailability of baseline information on the study area hindered study design and obscured optimal methodology. It is hoped that this study will aid future research expeditions focused on recording mammal abundance and richness by providing some baseline values and suggested methodology.

While some species may have gone undetected due to sampling limitations, others are potentially extirpated from the study area due to their large area requirements including species such as *Syncerus caffer nanus* (Boddaert, 1785) (Forest Buffalo) and *Panthera pardus pardus* (Linnaeus, 1758) (African Leopard). The absence of some species may also be the result of anthropogenic activities, such as extraction of non-timber forest products, charcoal production, encroachment, an increase in human population, and urbanization. Noise pollution may be another contributing factor to species absence with nearby surrounding communities and commuting vehicles (including an international airport 5 km away). Future studies might approach the viability of species reintroduction, especially after successfully improving the protection status of the Marshall Wetlands.

The natural spaces of Liberia have faced extreme trauma over the past several decades, such as civil conflicts and intensed deforestation, which have minimized some scientific studies and accurate reporting on biodiversity and mammal abundance. In this context, our results evidence the elevated potential of Marshall

Wetlands, one of several proposed protected areas being targeted for biodiversity conservation by the Liberian government. To combat the increasing threat to medium-sized and large mammals in Liberia's forests, conservation must remain a priority for the country's government as well as the local management of biodiversity-rich landscapes. Some solutions that have been shown to counteract loss of biodiversity include promoting awareness through conservation education for communities in and around proposed protected areas, providing alternatives to mammal exploitation, introduction of more sustainable livelihoods, and capacity development programs. Continued biodiversity research—such as what we performed in this study—is critical in measuring conservation program effectiveness and in guiding further conservation efforts. We believe that our results provide important baseline data on mammal abundance and biodiversity richness in the Marshall Wetlands that can be used for future monitoring programs and evaluation of mammalian populations and show the importance of this area for Biodiversity Conservation.

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ADDITIONAL INFORMATION

Conflict of interest

The authors declare that no competing interests exist.

Ethical statement

No ethical statement is reported.

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Author contributions

Conceptualization: PRP, AB. Data curation: AG, AFP. Formal analysis: AB, AFP, PRP. Investigation: AG, JP, HT. WC, CM, PRP. Methodology: AG, PRP, JP, HT. Supervision: PRP, CM, JD, JD. Project administration: JD, JD. Validation: AFP. Writing – original draft: AG, AB, AFP, CM, PRP. Writing – review and editing: AFP, PRP.

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Data availability

All data that support the findings of this study are available in the main text.

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